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METHOD AND DEVICE FOR CONTROLLING THE OPERATION OF AN AC MOTOR

FIELD OF THE INVENTION

This invention is generally in the field of electrical motors and relates to method and device for controlling the operation of an AC motor.

BACKGROUND OF THE INVENTION

It is known to control the output power of an electrical motor by rectifying the AC voltage of a power line and then transforming this voltage into rectangular pulses of variable width and direction. Such parameters as the width and frequency of pulses, as well as the period after which their polarity is reversed, are changed to provide generation of quasi-sinusoidal current in the motor, with a given frequency and amplitude. The period of polarity reversal determines rotational speed of the motor, while amplitude of current in the engine determines the torque it generates. This technique is described, for example, in the following patents.

U.S. Patent No. 4,366,429 discloses a variable speed controller for an alternating current induction motor. The controller reestablishes the start time for firing pulses and clock pulses in a circuit having a uniform frequency generator generating firing and clock pulses. Feedback from the stator terminals sets an oscillator with a sawtooth type ramp output. Subsequent feedback from the stator terminals are compared with the output of the oscillator in a comparator that establishes a time or phase shift in the generated output having the same frequency, for resetting the firing pulses so that the frequency of current to the stator winding is a function of the relationship between the stator and rotor positions, and of the current amplitude in the stator windings. Adjustment of the circuit parameters reduces the difference between the rotor and stator positions and optimizes stator current to maintain flux balance.

US Patent No. 6,313,600 describes an electric drive apparatus and method for controlling AC motors wherein the motor output is a function of the AC input power to the electric drive. Means are provided for detecting the voltage being supplied by the source of AC power to a drive circuit, and for controlling the output to the multi-phase AC load based on the detected power level. A controller monitors the motor voltage, current, and speed or frequency while also receiving a command for torque or torque-producing current. The method provides for the operation of the drive circuit in the event of either a partial or complete loss of AC input power. During such an occurrence, the controller will cause the circuit to generate sufficient negative torque to cause a power flow from the motor to the drive circuit to substantially equal the inherent losses in the drive and motor to avoid loss of energy from the DC filter of the drive circuit. Motor torque and speed can be quickly restored when the input power is re-established.

SUMMARY OF THE INVENTION

There is need in the art to provide an AC motor operable with reduced energy losses and also significantly reducing electrical disturbances generated in the power line by the motor and by the motor controlling device.

The present invention solves the above problem by providing a novel method and device for controlling the operation of a typical AC motor. The present invention can be used to optimize operation of air conditioners, electrical fans, washing machines, electrical pumps, and other electrical appliances.

The inventors have found that controlling the power output of a motor using the above-described known technique results in low efficiency of the motor. This is associated with the following: Generally, magnetic field is generated not only by current, but also by changing an electric field (voltage), such as sinusoidally varying voltage of the AC power line. According to the above method, a motor is supplied with rectangular pulses that practically have

no alternating component. Hence, a magnetic field is generated exclusively by the electric current. Moreover, the quasi-sinusoidal current created in the motor leads to discrepancy between the shape of the power line voltage and the shape of electric current drawn from the power line, which results in violation of standing standards for electrical utilities customers.

The main idea of the present invention consists of controlling the rotational speed and preferably also the torque of the motor, by transforming an input harmonic voltage (e.g., a power line sinusoidal voltage of e.g., 50Hz or 60Hx, or a sinusoidal voltage from generator) into a driving signal of the motor in the form of a periodic function (symmetric or asymmetric), each period being formed by two alternating signals (groups) of opposite polarities formed by gapless pulses each corresponding to the half-wave of the input harmonic voltage signal. The groups are such that at least one of them includes at least two unipolar pulses. As a result, a frequency of the so-obtained driving voltage signal is smaller than that of the input harmonic voltage, and accordingly the rotational speed of the motor is desirably decreased. The frequency f of the driving signal is determined by a number N of pulses in the period of the transformed signal, and can be calculated as $f=2f_0/N$, wherein f_0 is the frequency of the input harmonic voltage signal.

Its should be understood that the term ***"harmonic signal"*** signifies a wave of a single frequency waveform, indefinitely repeated in time, the only waveform integral and differential has the same waveform as itself. The classical example of the harmonic wave is a sinusoidal wave, its displacement can be expressed as the sine (or cosine) of a linear function of time and distance, or both. The typical alternative of the harmonic wave is a sequence of rectangular pulses, the Fourier transform of which presents multiple frequencies.

Preferably, the transformation of the input harmonic voltage signal also includes dividing each of the pulses (half-waves of the input signal) into a predetermined number of high-frequency sub-pulses. A number of sub-pulses inside each half wave pulse is selected to equalize the maximal amplitudes of

electric current generated by each half-wave pulse and to keep these amplitudes equal to a predetermined value.

The technique of the present invention also provides for circular flow of induction currents inside the motor, which significantly reduces passage of electromagnetic disturbances to the power line. This is associated with the following. When the voltage pulses are supplied to the motor, connection between the motor and the power supply unit (e.g., power line) is halted at the time intervals between the sub-pulses. During these time intervals, an additional path is to be provided for the remaining electric current through the motor. Generally, this may be achieved by directing the electric current to the power supply unit, or as utilized in the present invention, by causing the electric current circulation along a closed cycle inside the motor.

The transformation of the input voltage signal may be implemented by rectifying the harmonic input voltage signal (sinusoidal function) to produce a sequence of unipolar half-waves (pulses), and then arranging these voltage pulses in groups of one, two, or more pulses, while alternating direction of propagation of the pulses inside the motor. At the same time, each of the half waves may be divided into a predetermined number of high frequency sub-pulses.

There is thus provided according to one broad aspect of the invention, an electronic device for controlling the operation of an AC motor, the device being configured to be connectable to a voltage supply unit generating an input harmonic voltage of a certain frequency f_0 and to be connectable to the AC motor, and being configured and operable to transform the input voltage signal into a driving voltage signal in the form of a periodic function, the period of said function being formed by two groups of opposite polarities formed by a sequence of pulses each shaped as a half-wave of the input voltage signal, at least one of said groups including at least two gapless unipolar pulses, said periodic function having a frequency f smaller than the frequency f_0 by a predetermined factor defined by a number of the pulses in the period of the driving voltage signal.

According to another broad aspect of the present invention, there is provided a method for controlling the operation of an AC motor, the method comprising: controllably varying a frequency f of a driving voltage supplied to the motor, by transforming an input harmonic voltage signal of a certain given frequency f_0 into a driving voltage signal in the form of a periodic function with the period formed by two groups of opposite polarities, each of said groups including a desired number of pulses each shaped as a half-wave of the input voltage signal, and at least one of said groups including a sequence of the at least two gapless unipolar pulses, said periodic function having the frequency f smaller than the frequency f_0 by a predetermined factor defined by a number N of the pulses in the period of the driving voltage signal.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic illustration of a motor system utilizing a motor controlling device of the present invention;

Fig. 2A exemplifies a typical AC voltage signal;

Figs. 2B to 2D show three examples, respectively, of a driving voltage produced by transforming the AC voltage of Fig. 2A using the technique of the present invention;

Fig. 3 exemplifies a configuration of the device of Fig. 1;

Fig. 4 exemplifies a driving signal produced by the device of the present invention;

Fig. 5 schematically illustrates how the present invention is used to regulate the voltage supply to the commutator-type AC motor, depending on the relative position of brushes and commutator of the motor;

Fig. 6A is a flow diagram of the main operational steps of a method according to the invention for controlling the operation of an AC motor;

Fig. 6B is an example of the method according to the invention;

Figs. 7A to 7C schematically illustrate how the technique of the present invention is used for correcting the shape of an electric current through an AC motor; and

Fig. 8 shows a specific example of the implementation of the device of Fig. 3.

DETAILED DESCRIPTION OF THE INVENTION

Referring to **Fig. 1**, there is schematically illustrated a device **100** of the present invention for controlling the operation of an AC motor **120**, for example a single phase motor. The device **100** is interconnected between the motor **120** and a power supply unit **122**. The latter is an AC voltage supplier (such as a power line), generating an input harmonic voltage signal $V_{in}(t)$ of a certain given frequency f_0. The device **100** is configured for processing the input voltage signal V_{in} coming from the power supply unit **122** to produce a driving voltage signal $V_{dr}(t)$ to the motor **120**, which has a desired frequency f_1 smaller than the input signal frequency f_o by a desired factor. By this, the speed of the motor rotation is desirably controlled (decreased).

The device **100** is configured to transform the harmonic input voltage signal V_{in} into the periodic function $V_{dr}(t)$ with the period being formed by two group of pulses of opposite polarities, respectively, such that each of these groups includes a predetermined number of pulses each shaped as a half-wave of the input signal, and at least one of these two groups includes a sequence of the at least two unipolar gapless pulses. The following are several specific but not limiting examples of the operation of the device **100** of the present invention.

Fig. 2A exemplifies the typical input voltage signal (sinusoidal function) $V_{in}(t)$ having a frequency f_0. **Figs. 2B-2D** exemplify different driving voltage

signals $V^{(1)}_{dr}(t)$, $V^{(2)}_{dr}(t)$ and $V^{(3)}_{dr}(t)$ of frequencies f_1, f_2 and f_3, respectively, obtained by transforming the input voltage signal $V_{in}(t)$ according to the technique of the invention.

In the example of **Fig. 2B**, the input voltage signal $V_{in}(t)$ is transformed into the periodic symmetric function $V^{(1)}_{dr}(t)$ with a period formed by two signals or groups S_1 and S'_1 of opposite polarities, each including a sequence of two unipolar pulses **P**, each pulse corresponding to the half-wave of the input voltage signal. Here, the period of the driving voltage function includes 4 pulses **P**.

In the example of **Fig. 2C**, the driving voltage signal $V^{(2)}_{dr}(t)$ is also a periodic symmetric function, but with each of the groups S_2 and S'_2 including a sequence of three such unipolar half-wave pulses **P**. The period of the driving voltage function thus includes 6 half-wave pulses **P**.

Fig. 2D shows an example where the input voltage $V_{in}(t)$ of Fig. 2A is transformed into the driving voltage $V^{(3)}_{dr}(t)$ in the form of a periodic asymmetric function, in which one group S_3 is a sequence of two unipolar pulses **P** (half-waves) and the other group S'_3 includes the single pulse **P**, the entire number of pulses **P** in the period of the driving voltage signal being equal to 3. In this example, the numbers of unipolar half-waves (pulses **P**) within the two groups of opposite polarities are different.

As clearly seen in the above examples, the frequency of the driving signal is smaller than that of the input signal: $f_1=f_0/2$ (Fig. 2B); $f_2=f_0/3$ (Fig. 2C), $f_3=2f_0/3$ (Fig. 2D). Generally speaking, the frequency of the driving voltage signal V_{dr} depends on the number N of pulses in the period of the driving voltage signal obtained by the transformation of the input voltage signal, and can be calculated as $2f_0/N$.

Fig. 3 exemplifies the configuration of the device **100**. The latter includes such main functional utilities as a rectifier utility **124** and a pulse grouping utility **126**. The rectifier **124** is configured and operable to transform an input harmonic signal $V_{in}(t)$ into a sequence of unipolar (positive or negative) gapless pulses **P** each of a half-wave shape of the input sinusoidal signal $V_{in}(t)$. Such a rectifier

124 may utilize a conventional diode bridge assembly. The pulse grouping utility **126** is configured and operable to arrange these voltage pulses **P** in groups of alternating polarities, the group including a desired number (one, two, or more) unipolar pulses **P**, thereby producing a driving signal $V_{dr}(t)$ of a desire frequency having a desired number N of pulses in the period, to be applied to a motor **120**. Such a pulse grouping utility may utilize a transistor bridge to create the groups of half-waves of one or the other polarity.

Preferably the same pulse grouping utility **126** is configured and operable to perform a pulse shaping, consisting in dividing each of the half-wave pulses into a predetermined number of high frequency sub-pulses. This is exemplified in **Fig. 4** showing a driving voltage function $V_{dr}(t)$ configured generally similar to that of Fig. 2B, but in which each pulse **P** is divided into sub-pulses **L**. The number of the high frequency sub-pulses inside each half-wave pulse is adjusted to equalize the maximal amplitudes of electric current generated by the half-waves and to keep them equal to a predetermined value.

The following is a specific example of using the technique of the present invention for controlling the operation of an AC motor used in the ventilator of an air conditioner. In this specific example the AC motor is supplied by the power line, V_{in}=220V, f_0=50Hz. The output power of the motor is 400W. The controlling device of the present was interconnected between the power line and the motor, so as to selectively provide the motor operation with one three modes corresponding to the rotational speeds of, respectively, R_0=3000 revolutions per minute, R_1=1500rev/min, R_2=1000rwev/min. In this specific example, the controlling device utilized the 16-digits processor commercially available from Atmel, USA.

The first operational mode, R_0=3000rev/min, was obtained as a result of direct supply of the input voltage to the motor (i.e., inoperative position of the controlling device, $V_{in}=V_{dr}$), the electric current through the motor being of about 2.5A (maximal amplitude). The second operational mode, R_1=1500rev/min, was obtained by operating the controlling device to transform the input voltage signal

of f_0=50Hz into a driving voltage of f_1=25Hz, namely with each group including two unipolar half-wave pulses (generally similar to that of Fig. 2B). Moreover, each of these pulses was divided into sub-pulses such that the sub-pulses' duration within the pulse filled of about 50% of the respective half-wave pulse. At this mode, the electric current through the motor was about 1.25-1.4A. The third operational mode, R_2=1000rwev/min, was obtained by transforming the input voltage signal into a driving voltage of f_2=16. 7Hz, namely each group of the driving voltage function including three half-wave pulses (generally similar to that of Fig. 2C). Each of these half-wave pulses was divided into sub-pulses each providing about 30-40% filling of the respective pulse. The electric current through the motor was about 1-1.1A.

Turning back to **Fig. 4**, it should be understood that this figure exemplifies the driving voltage during the motor operation. Preferably, during the start of a motor, the frequency and duty factor of the sub-pulses **L** are changed such that initially the frequency and duty factor of the sub-pulses **L** supplied to the motor are set to their maximal and minimal values, respectively. To this end, each half-wave pulse **P** is divided into the maximal possible number of sub-pulses **L**, each of a minimal width, and then the frequency of the sub-pulses is gradually decreased and their width increased, until they reach the prescribed values. As the motor accelerates, the frequency of the sub-pulses is decreased, and the width of the sub-pulses is increased. During the breakage (discontinuity) of the motor, the process goes into reverse direction.

It should be noted that when using a commutator-type motor (the construction and operation of which are known *per se*), the voltage supply to the motor is halted during a time period of unstable contact between the brushes assembly and the commutator assembly of the motor. To this end, a sensor is used for determining a relative position of the brushes assembly relative to the contacts of commutator. Such a sensor may for example be a photosensor formed with slots arranged to match the gaps in the commutator's plates. **Fig. 5** schematically illustrates this feature of the invention. At moment **A**, just prior to

the brush passing away from the commutator plate, the voltage supply is halted; an electric current I through the motor is thus decreasing, and at the moment the brush discontinuity with the commutator plate reaches its minimal value, at which no sparking is created. Thereafter, the voltage supply to the motor is re-established. It should be noted that voltage supply interruptions to the collector is independent of the half-waves movement. During the time period of the half-waves passage, up to 10 and more interruptions may occur, associated with the brush passage along the collector.

Fig. 6A is a flow diagram of the main steps in a method of the present invention for controlling the operation of an AC motor. The method is aimed at adjusting a frequency f of a driving voltage $V_{dr}(t)$ supplied to the motor. First, an input harmonic voltage signal $V_{in}(t)$ of a given frequency f_0 is provided, which is typically a sinusoidal signal. This voltage signal $V_{in}(t)$ then undergoes processing to be transformed into a periodic function of the driving voltage $V_{dr}(t)$ with the period formed by two groups (signals) of opposite polarities. Each of the two groups includes a desired number (either the same for the two groups or not) of pulses, each pulse shaped as a half-wave of the input voltage signal $V_{in}(t)$, at least one of the two groups including a sequence of the at least two gapless unipolar pulses. This results in that the frequency f of the driving signal $V_{dr}(t)$ is smaller than the frequency f_0 of the input signal $V_{in}(t)$ by a predetermined factor defined by a number N of the pulses in the period of the driving voltage (the total number of half wave pulses in the two groups).

Fig. 6B exemplifies the steps of the processing procedure: The input voltage signal $V_{in}(t)$ undergoes a first processing consisting of rectifying to thereby produce a sequence of gapless unipolar half wave pulses. Then this sequence undergoes a second processing consisting of arranging these pulses in the groups of alternating polarities, thereby obtaining the driving voltage function $V_{dr}(t)$. As shown in the figure in dashed lines, the second processing preferably also includes a pulse shaping applied to each of the half-wave pulses to divide the pulse into a predetermined number of the high frequency spaced-apart sub-

pulses. The number of the high frequency sub-pulses inside the half-wave pulse is selected to equalize the maximal values of amplitudes of the electric current through the motor generated by the half-waves and to keep the amplitudes equal to a predetermined value. The number of the sub-pulses may vary depending on a position of the corresponding half-wave inside the group.

It should be noted that for each group, the half waves (pulses) may for example be divided into a number of sub-pulses that varies depending on the position of the half-wave inside the group. For example, the width of the sub-pulses in the second half-wave is 1.5-2 times narrower than that in the first half-wave, and the width of the sub-pulses in the third half-wave is 1.5 times narrower than in the second half-wave. The electric current of the motor is measured, during each half-wave of the input harmonic voltage, and the width of sub-pulses inside each half-wave is so adjusted that the maximal currents during each half-wave are equalized and kept equal to a preset value.

A time interval, during which the high frequency sub-pulses are formed, is limited to a certain zone inside each half-wave (pulse). In between the high frequency sub-pulses, energy flows circulate within the motor and the motor control device. As described above, this is used to provide an additional path for electric current, remaining in the motor as a result of disconnection between the motor and the power supply unit during the time intervals between the sub-pulses.

The division of the half-wave pulse into high-frequency sub-pulses may be applied not along the entire pulse, but only to a given zone within the pulse and this zone has a predetermined position relative to the start point of the half-wave (predetermined delay) and a certain prediction with respect to the end point of the respective half-wave pulse, while the width of the sub-pulse at the beginning of each half-wave pulse is larger than the width of the sub-pulse at the end of the half-wave pulse. While producing a change in the direction of propagation of half-waves in the motor (a change in polarity), one or more demagnetizing sub-pulses are supplied to the motor. In other words, the

arrangement of sub-pulses in the driving signal is such that each group of unipolar half waves is followed by a narrow demagnetizing sub-pulse of opposite polarity.

The technique of the present invention also provides for correcting such a parameter of the motor as $cos\varphi$ (characterizing the current and voltage bias in time). When the voltage passes through zero, i.e., when the direction of half-waves propagation changes from one to the other, the electric current through the motor should go to zero. Otherwise, a retarding moment is created in the motor. This is achieved by measuring this parameter (preferably continuously measuring), and appropriately changing (decreasing) the width of the sub-pulses in the last half-wave pulse of the group such that at the moment of switching the voltage direction (polarity) the electric current through the motor is equal to zero.

Practically, the shape of the electric current through the motor should be corrected. This is associated with the following: Experiments have shown that during the motor operation, especially the high-power motor, certain fluctuations occur in various half-waves of the electric current shape (time profile) from the standard sinusoidal form. The nature of this phenomenon is known as being associated with the pulsation of magnetic fields in the motor during the rotational speed of the motor decreases. This is schematically illustrated in **Figs. 7A-7C** showing, respectively, the shape of periodic driving voltage signal $V_{dr}(t)$ (only one group being shown in the figure), the shape of actual electric current $I(t)$ through the motor (when no means are used for the shape correction), and a desired shape of the electric current $I'(t)$ that is to be approached as much as possible. To compensate for this phenomenon, the width of sub-pulses (not shown here) inside the half-wave pulses should be controllably varied such as to obtain the desired harmonic (sinusoidal) form of the electric current inside each of the half-wave pulses. To this end, the actual values of the electric current are measured and the current function is compared to a standard sinusoidal curve, and the width of the sub-pulses in each half-wave pulse is appropriately adjusted to obtain the best fitting between the shape of the actual electric current and the

standard sinusoidal curve. If the amplitude of the electric current exceeds the required value, then the width of the sub-pulses is decreased, and if the amplitude of the current is less than the required value, then the width of the sub-pulses is increased. It should be noted that a time delay of the control signals in relation to the measured amplitude of the current it taken into account.

To regulate the rotational speed of the motor, the rotational speed is measured (preferably continuously) and the number of half-waves (pulses) in the group is changed such as to maintain the rotational speed at a required value. For example, if the speed exceeds the required value, a number of the half-waves in each group (positive and negative groups) is increased, and, if the speed falls below the required value, a number of the half-waves in the groups of the same polarity is decreased.

Considering a commutator-type motor, an additional voltage interruption is carried out during the brushes' assembly passage between the contacts of commutator. At the start of the motor, the half-wave pulses are divided into spaced-apart narrow sub-pulses of high frequency. Then, the width of the sub-pulses is increased. In some cases, the start process also includes changing the frequency of the sub-pulses. Affecting a change in the sub-pulses frequency and width is aimed at obtaining a relative slow and smooth increase of the electric current and its torque in the motor.

Reference is made to **Fig. 8** that shows a specific, but not limiting example, of the implementation of a device **1000** according to the invention. A rectifier **124** (e.g., diode bridge) is provided being connected to a power line to transform a sinusoidal voltage $V_{in}(t)$ of the power line into a sequence of gapless unipolar half–waves (pulses). The output of the rectifier **124** is connected to a pulse grouping utility **126** that is associated with comparators **2** and **3** for signaling, respectively, the beginning and the end of the positive half period of the sinusoidal voltage, and the beginning and the end of the negative half period of the sinusoidal voltage.

The pulse grouping utility **126** includes a narrow pulse former **4**, a frequency divider **5**, a controller **6**, generators of high frequency pulses **7** and **8**, pulses summators **9, 10** and **12**, switching devices (transistors) **13, 14, 15, 16, 17, 18, 19**, and **20**, a transformer **21**, diodes **23, 24, 25, 26**. Transistors **17, 18, 19** and **20** form the transistor bridge. To this end, these transistors are connected to each other such that when transistors **17** and **19** are opened, the half-waves of the input voltage created in the diode bridge propagate in one direction, and when transistors **18** and **20** are opened the same half-waves created in the diode bridge propagate in the opposite direction. This results in a half-waves alternating voltage. While producing a change in the direction of propagation of half-waves in the motor (a change in polarity), one or more demagnetizing sub-pulses are supplied to the motor. In other words, the arrangement of sub-pulses in the driving signal is such that each group of unipolar half waves is followed by a narrow demagnetizing sub-pulse of opposite polarity. This is associated with the following. When the voltage half-waves pass through the windings of the motor, a complicated process of transformation of the electric current and voltage into magnetic fields of rotor and stator takes place. These fields are pulsating. In this connection, at the moments of passage from one half-wave to another, ejection of electric current is possible, which can be suppressed by pulses of the opposite polarity. To this end, keeping the opposite transistors opened for a short period of time is sufficient.

The controller utility **6** is associated with appropriate sensors or measuring units (not shown) configured and operable for measuring an electric current through the motor during each half wave of the input voltage signal thereby enabling to determine a time profile of the electric current function; measuring $cos\varphi$ of the motor; as well as measuring a rotational speed of the motor.

Inputs of the rectifier **124** are connected to the power line, and its outputs are connected to the inputs of the switches **17, 18, 19, 20**. Outputs of the switches **17** and **20** are connected to one of lead wires of the motor **120**, while outputs of the switches **18** and **19** are connected to another lead wire of the motor.

Controlling inputs of the switches **17, 18, 19, 20** are connected to outputs of the switching devices **13, 14, 15, 16** driven by the controller **6**, while inputs of the switching devices are connected as follows: Inputs of the switching device **13** are connected to outputs of the summators **9** and **12**; inputs of the switching device **15** are connected to output of the summator **10** and to inverting output of the summator **12**; inputs of the switching device **14** are connected to output the frequency divider **5** and to output of the comparator **3**; inputs of the switching device **16** are connected to output of the frequency divider **5** and to output of the comparator **2**. Controlling inputs of the switching devices are connected to outputs of the controller **6**. Inputs of the summator **9** are connected to outputs of the comparator **2** and the generator **7**, while inputs of the summator **10** are connected to outputs of the comparator **3** and the generator **8**. Output of the comparator **3** is also connected, through the narrow pulse former **4**, with input of the frequency divider. Controlling inputs of the generators **7** and **8** are connected to outputs of the controller. The diodes **23-26** are connected in parallel to the switches **17-20**.

The device **1000** operates as follows. The power line AC voltage $V_{in}(t)$ is rectified by the rectifier **124** which is realized, for example, as a full wave rectifier utilizing high-speed diodes. The so-rectified signal is in the form of a sequence of gapless unipolar half waves of sinusoidal voltage, and is transmitted to inputs of the switches. When switches **17** and **20** are closed, the half waves are passing through a motor **120** without distortions, providing that the period during which the switches stay open is a multiple of a half period of the input AC voltage. When switches **17** and **20** are closed, the switches **18** and **19** are open. When the switches **18** and **19** are closed for the period that is a multiple of a half period of the input voltage, while the switches **17** and **20** are opened, the voltage half waves pass through the motor **120** in the reverse direction. A time diagram of voltage applied to the motor, in the case when the period of the switches staying closed is 2 times half period of the input voltage, as exemplified in Fig. 2A. The switching period, this is the period during which the switches stay

either open or closed, is determined by the comparators **2** and **3**. The comparators generate rectangular pulses whose width is approximately equal to a half period of the input voltage. If the switching period is equal to a half period of the input voltage, signals from the comparators are applied directly to controlling inputs of the switches **19** and **20**, through the switching devices **15** and **16**. The signals from the comparators that are applied to controlling inputs of the switches **19** and **20** are combined with pulses from the high frequency pulse generator by the mixers (summators) **9** and **10**. Opening and closing of the switches **18** or **17** divides each half wave into high frequency sub-pulses, the number of which is controlled by the frequency of the generator. At the same time, since the switch **20** remains closed during the half wave period, while the switch **17** operates in the pulse mode, when the switch **17** is opened, current accumulated in the motor **120** flows in the closed circuit, through the switch **19** and the diode **26**. The pair of switches **18, 19** operates similarly. In the case when the switches are driven by signals from the comparator that have passed through the frequency divider **5**, the switching period is a multiple of a half wave period of the input voltage (for example Fig. 2C). Practically, this means that, since the ratio of the switching period to the period of the input voltage is equal to the number of the unipolar half wave sinusoidal pulses in the group, rotational speed of the motor **120** decreases proportionally to this number. Decrease in the rotational speed of the motor **120** results in an increase of electric current in the motor's windings. Indeed, at a constant feeding voltage, the amount of electrical energy consumed by the motor remains the same, regardless of the rotational speed, while at the lower speed it cannot be fully transformed into mechanical energy. Varying the number and width of sub-pulses inside each half wave is used as the means of controlling the amount of electrical energy consumed by the motor. At the same time, as experiments have shown, inside a group, current is increasing with each successive half wave, which is due to increase in residual magnetization of the motor's core. To compensate for this effect, variable width of pulses inside a half wave is used (for example Fig. 4).

As described above, the varying width of the sub-pulses may also be used for regulating the shape of the electric current through the motor. To this end, the controller operates to compare the actual values of the electric current (i.e., the electric current time profile) with a theoretical sinusoidal curve and to generate data indicative of a corrected value of the sub-pulse width for compensating for mismatching between the actual profile and the theoretical curve. To compensate for commutator sparking at moments just prior to the breakage of contact between the commutator plate and the brush, the voltage supply to the motor is halted for a short period of time. As a result, an electric current in the motor coil falls, there is no voltage on the brush, and therefore there is no sparking at the moment of the contact breakage. To measure the rotational speed of the motor, the controller effects a change in the number of half-wave pulses in the voltage signal group of one polarity. The higher the number of half-wave pulses in the group, the lower the frequency of transformation, while the number of half-wave pulses in the group of opposite polarities may and may not be the same, i.e., the driving voltage function may and may not be symmetric. To provide a smooth start of the motor, the controller operates to provide narrow high-frequency sub-pulses in the driving voltage. While the motor operation accelerates, the width of the sub-pulses is increased. Thus, the present invention provides for controlling the operation of an AC motor to provide desired rotational speed of the motor and preferably also desired electric current through the motor. This is achieved by transforming a typical harmonic voltage signal of one frequency into a periodic signal of a smaller frequency.

Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope defined in and by the appended claims.